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Patentanmeldung Nr. | Patent application No. | Demande de brevet n°

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Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
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Holographic data storage

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Holographic datastorage

Simplified method for readout of holographic storage media

Introduction

In holographic datastorage systems data stored in or to be recorded in a medium is usually organized in pages (data pages). For readout a readout beam impinging on a recorded holographic medium re-creates under the proper circumstances a previously recorded data page in the form of an image which can be detected by and readout via a pixilated detector like a two-dimensional array of light detectors (for instance a CMOS or CCD image sensor).

Problem

Due to variations in the diffraction efficiency of the recorded datapages, power fluctuations in the output power of the laser source, or other causes, the detected light level can vary. Furthermore, due to misalignment errors between image and pixilated detector or noise sources, gray levels and in plane variations may occur over the pixilated detector, which requires that the detector signals are being transported in analogue values to an A/D-converter, and after that through A/D conversion converted to the digital domain, requiring a bit depth of some 8 to12 bits to get enough dynamic range and resolving power/resolution. After transformation to the digital domain, the actual data are derived through the use of error correction codes, etc.

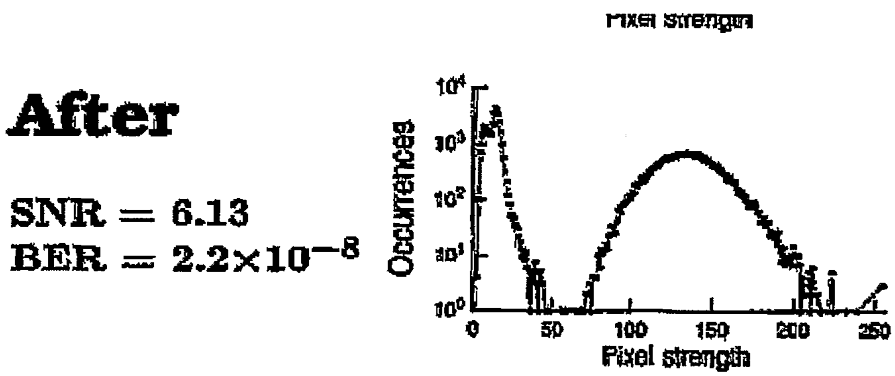
Since it is commonly known that image-sensors have limited output-signal bandwidth per row or column of the array, introducing an increased bit depth for the A/D conversion, will lead to a required bandwidth, which is larger than the available bandwidth of the image-sensor thereby limiting the total user bitrate out of such a holographic data storage system. The limiting effect on the bitrate of a holographic data storage system is in part due to the limitations of the image-sensor.

Solution and some embodiments

We propose in the method described below to circumvent this problem by introducing a power balancing method for the laser power in the readout beam, and the use of only a 1 bit

output per detector element through a simple decision circuit and thereby simplifying the output substantially.

Consider figure 1 which shows the typical distribution of gray-levels in a holographic system **Ref:Burr et al.Optics letters Vol 23 No4 (1998) pages 289-291**



One can see that there is a clear two-sided distribution

The so-called pixel-strength in this paper is indicative of the output value of the individual detectors in the array, and in order to denote a specific detector output representing a first and second output-level (for example a one and a zero, or on and off) a decision-level has to be set discriminating between these two output levels. For instance in this example, this would lead to a pixel strength value of 60-70.

The usual content of a data page to be recorded is a 50-50 distribution of on and off pixels. During readout the same 50-50 distribution would be expected in the image, yielding an average total load on the detector which should be the same for each page, i.e. on the average the same distribution is on the detector, however the distribution in the page itself is of course random going from one page to another. Due to the said misalignment errors between image and pixilated detector or noise sources, gray levels and in plane variations may occur over the pixilated detector, which results in a different distribution of on and off pixels.

The method we propose now is the following. Suppose we have devised a pixilated detector having a number of detector elements. After threshold level detection the individual detector ~~elements can only have a two level output representing the binary state of a bit (a 1 or a zero).~~

In a so-called threshold detection circuit, the output signal of a detector element crosses a certain threshold level (two-sided) the output of a differential amplifier, which may be built into the detector element, will flip from a first output level for a first impinging light intensity range to a second output level for a second impinging light intensity range.

If one keeps track of the number of on-states in the detector array vs. the number of off states and one adjust the laser power of the readout beam in such a way until these counts are equal, representing the 50-50 distribution, one has achieved the following things at the same time

1. a threshold level has been defined by adjusting the laser power
2. the conversion from the analogue domain to the digital domain has been done in the detector
3. the bit decision is done in the detector itself
4. noise contributions, either through fluctuations in the laser power, detector noise, or transportation in the detector and henceforth have been diminished
5. No analogue high speed amplifiers are required
6. the required bandwidth per row or column of the detector has been decreased drastically (going from 8-12 bit sampling to 1 bit)
7. the additional processing power in the digital domain has been reduced considerably
8. the power consumption of the system has been reduced

The adaptation of the laser power in the readout beam has in worst case to be on a data page to data page basis. In more controlled recording and or readout conditions, one can use the same laser power (or threshold) for several pages, book or a whole medium.
In a feed forward way one can also use a look-up table to pre-program the required laser power per individual data page, several data pages, book or the whole medium.

It is preferred that the number of detector elements having the first output level differs not more than 20% with the number of detector elements having the second output level.

It is also possible that only one threshold detection circuit is used for all detector elements. A serial readout of the detector array is then required.
Another possibility is using a detection circuit per row or column of detector elements of the detector array.

CLAIMS:

1. A holographic data storage device for readout of data from a holographic data storage medium using a readout beam and a detection system, the detection system comprising a detector having a number of individual detector elements and a threshold level detection circuit, the threshold detection circuit having a first output level for a first impinging light intensity range and a second output level for a second impinging light intensity range.

2. A holographic data storage device according to claim 1 using a readout beam having a light intensity and a light intensity control circuit for adjusting said light intensity in such a way, that the number of detector elements having the first output level is about equal to the number of detector elements having the second output level.

Method to detect high resolution data below the detector limit in holographic storage devices

Introduction

In state of the art holographic data storage devices, it is common use to store the data bits organized in pages (data pages) in a holographic storage medium.

These data pages consist of arrays containing individual bits of about equal size.

In the read-out phase of such a holographic datastorage medium an image reproduced is closely mapped onto a pixilated detector (for example a two-dimensional detector array), where usually a one to one bit to pixel match exists. In some cases, to reduce the burden of careful alignment between bits in the image and the pixels in the detector, an over-sampling method is used, thereby using a plurality of detector- pixels to match one bit. Image processing is subsequently being undertaken to deduce the actual data bits in the data page.

Problem

Both methods suffer from the disadvantage that the pixels in the detector are correlated in at least a one to one fashion with the data in the medium, and hence the cost of the detector goes up dramatically if one wants to increase the number of bits per data page.

Solutions and some embodiments

We propose a method here where there are more bits in the data page correlated with the one pixel in the detector array. This can result in a lower bill of materials in the optical drive, and furthermore, also can lead to additional features such as forward compatibility and noise reduction of the system.

The reader is referred to figure 1, in which we have sketched the principle of the method.

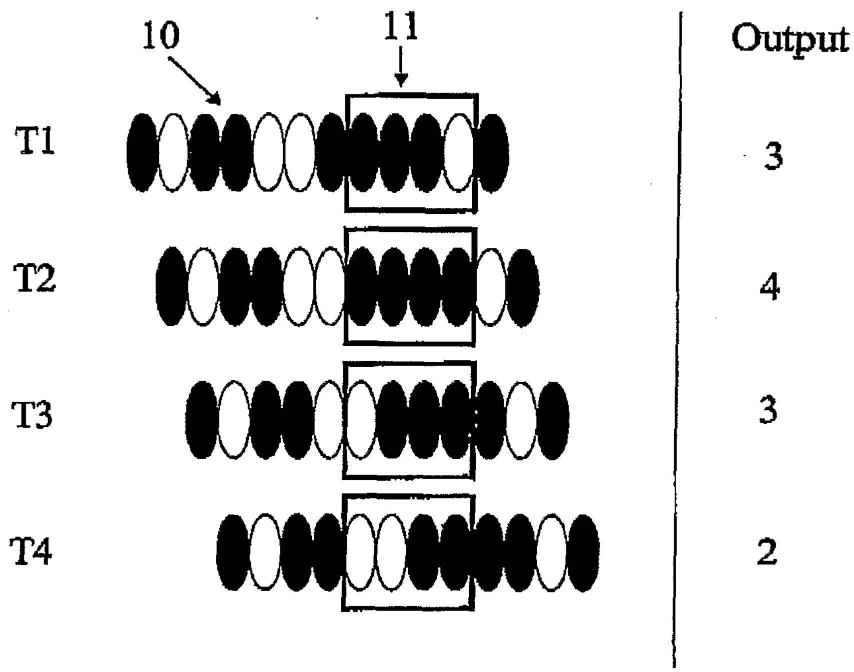


Figure 1

Consider a holographic data storage device for reading out data bits organized in pages from a holographic data storage medium, said device comprising a detector array having detector elements having a first size in a first direction and a second size in a second direction perpendicular to said first direction, for reading out an image of a data bits having an imaged bit size having a third size in said first direction at least a factor two smaller than said first size, were said image of data bits and said detector array are scanned with respect to each other in the first direction.

Consider a datasequence 10 of individual bits, in which each bit can have two stages (for example on and off, or high and low). Consider these bits as being one row out of many in a 2 dimensional image of a data page recorded into a holographic data storage medium in the appropriate way. Suppose we have devised a detector 11, of substantial larger area than the minimum size of the modulations in the datasequence. At moment/point in time T1 a particular subset of that bitsequence is imaged upon this detector and a certain detector output is being generated. In this example, were a shaded area is indicative of high intensity and a light area of low intensity in the imaged databit sequence, the output of the detector at T1 is 3. Suppose in a later readout timeslot the image of the databit sequence has shifted by one bit

in the sequence, and from that we detect at a moment/point in time T2 a value of 4. Going on, the output at T3 is the value 3 and at T4 the value 2.
If we look at what has happened and put this in below truth table we can deduce the following logic

Left bit in	right bit out	delta (in - out)
1	1	0
1	0	1
0	0	0
0	1	-1

Table 1. Truth table corresponding to figure 1

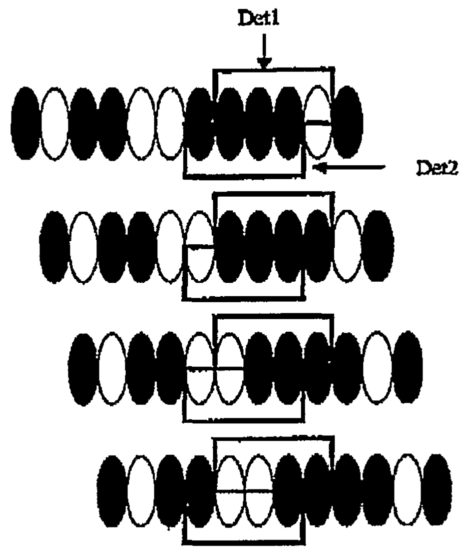
Rather than taking the absolute value of the detector output, we can derive from the difference between the values of the individual moments in time the transitions that have occurred, and hence what the individual bits in the sequence have been.
In this way we can reconstruct the datasequence in total, whereas the resolution of the detector array is less than the individual bits in the imaged datapages.

If one considers the pitch of the individual detector elements in the detector array and define that distance being equal to 'a1' and the pitch databits in the imaged datapage defined as being 'b1', then the required number of steps to be taken the deduce the complete sequence again is being given by 'a1/b1'.
When this is substantially an integer the system can be made relative simple using discrete steps to readout the datasequence.
When this is not an integer one can also perform a continuous scan, while using for example a clock regenerated from the data to define the proper readout moment.

The scanning can be introduced automatically if one considers for example a holographic data storage system that is based on angular multiplexing. In such a system the individual data pages are recorded as multiplexed holograms through varying the angle between the referencebeam and the encoded databeam.
During readout an angular scanning device, like a galvano mirror, can be used to set the correct angle of the readout beam and hence read out the recorded datapage. If one scans this galvano mirror within a small angle around the optimum required for each datapage one also automatically gets a displacement of the image in the detectorplane and hence this results in the required scanning described as above.

One can also put a displacement element in front of the detector array. Examples of a device that can displace the image over the detector array are a galvano mirror, an LC based wedge device, or an electrowetting based deflection device.

An enhancement of the method described above is shown in below figure 2.
Consider a holographic data storage device for reading out data bits organized in pages from a holographic data storage medium, said device comprising a detector array having detector elements, each detector element having detector segments, each detector segment having a first size in the first direction and a fourth size in the second direction, said detector segments being mutually displaced in said first direction, said displacement being less that said first size of said detector segment.



	Output Det1	Output Det2	difference Det2-Det1
T1	3	4	-1
T2	4	3	1
T3	3	2	1
T4	2	2	0

Figure 2.

In this method we have not used a single detector element as in the previous description, but one divided into two detector segments (preferably halves) denoted as Det1 and Det2 and in a similar matter positioned and scanned the datasequence over this set of detectorsegments and found a truth table as described in the left of the above figure. If the detector layout is arranged in such a way that the difference signal between both detector segments are measured electronically immediately (rather than first reading out the values per detectorsegment individually and then subtracting the values) one has the additional advantage of subtracting (like common-mode rejection) for example background noise due to the laser source, straylight, or darknoise of the detector and hence end up with a much cleaner signal.

CLAIMS:

1. A holographic data storage device for reading out data bits from a holographic data storage medium, said device comprising a detector array having detector elements having a first size in a first direction and a second size in a second direction perpendicular to said first direction, for reading out an image of a data bits having an imaged bit size having a third size in said first direction smaller than said first size, were said image of data bits and said detector array are scanned with respect to each other in the first direction.

2. A holographic data storage device according to claim 1, wherein said third size a at least a factor two smaller than said first size.

3. A holographic data storage device according to claim 1, each detector element having detector segments, each detector segment having a first size in the first direction, said detector segments being mutually displaced in said first direction, said displacement being less that said first size of said detector segment.

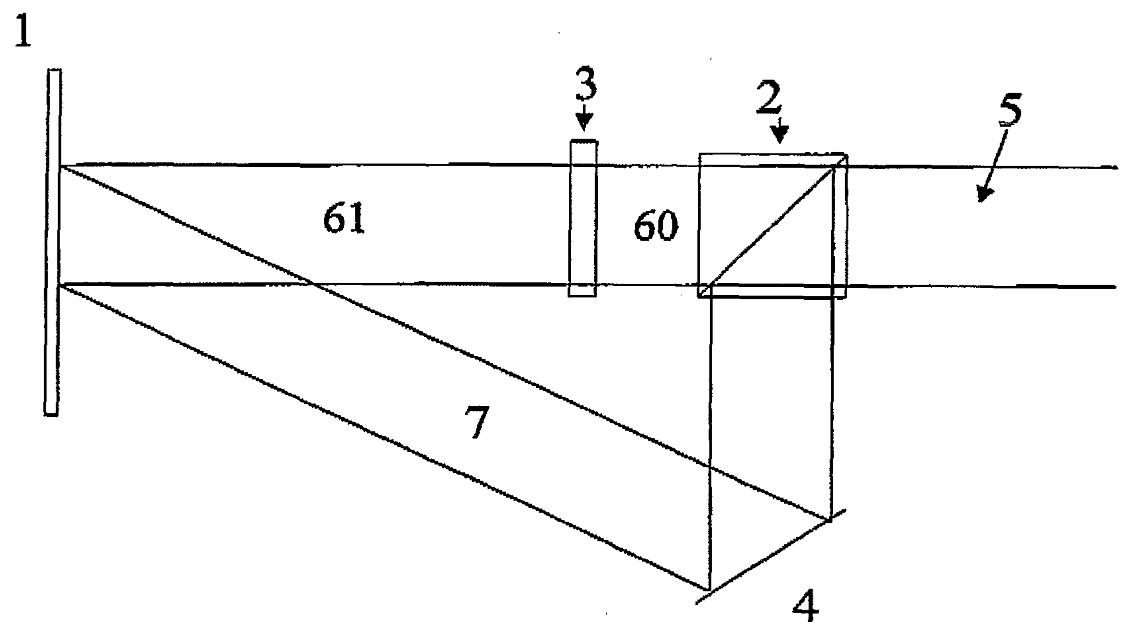
4. A holographic data storage device according to claim 3, wherein each detector segment has a fourth size in the second direction, said fourth size being smaller than said second size.

Method to encode pages in holographic storage systems

Background

In holographic storage systems as they have been developed recently, a 2-dimensional data page is stored through interference of two coherent lightbeams coming from a common laser source (5) (see also the setup in the schematic figure below), where one of the beams is encoded by a data encoder (3), for instance a two dimensional lightmodulator (2D-LM). Although here a transmittive 2D-LM is shown, also a reflective type can be used, resulting in a different setup.

Two beams 60 and 7 are formed by means of a beamsplitter 2 and mirror 4. A first beam 60 (data beam) is propagating along a first optical axis through a 2D-LM resulting in an encoded data beam (61) and a second beam (7) (reference beam) is propagating along a second optical axis. A suitable holographic storage medium 1 is placed at the intersection between said two beams and preferably through index of refraction changes in the medium, a "grating" pattern (or interference pattern) is created in the volume of the medium. Readout of a recorded data page can be done by impinging a readout beam (7) on the medium, which through refraction of this laserbeam by the grating in the medium creates an image beam, which image beam can be used to create an image of the recorded data page. This image can be projected onto a pixilated detector.



There are several methods to store several of these datapages in the same volume, which can be individually read out by changing either the impinging angle of the reference beam, wavelength, the polarization, etc, etc. The reader is referred to existing articles on holographic datastorage.

Problem

The amount of individual data bits in a page is limited by several factors, but the main reason is the number of individually addressable elements in the data encoder, here a 2D-lightmodulator. An example of a 2D-lightmodulator can be an two-dimensional Liquid Crystal modulator, which can have individually addressable elements up to several megapixels. Although a lot of progress has been made in this area, mainly due to the development of these elements for projection-displays, there are still several severe shortcomings with these devices.

1. First of all the size of these modulators requires a lot of space and extended homogenous laserbeams, which are difficult to realize especially if one would like to miniaturize the storage system.
2. In the case of a high number of pixels complex electronics is required which leads to additional cost and powerconsumption

3. A high pixelcount in the modulator is more difficult to make than a lower one, thus increasing the cost of the device

Holographic storage media are usually cumulative ones, meaning that for example the change of index of refraction is proportional to the total amount of photons impinging on the material. This proportionality relation is not always a linear dependence, however is always monotonically increasing. To maximize the number of datapages that can be stored, a careful balance is to be made between the ultimate index of refraction change (index budget) that can be achieved versus the consumption of refractive index change per data page. In this trade-off the upper limit of pages that can be stored, is determined by the diffraction efficiency of an individual data page and the noise in the system. As an example consider a material which upon complete illumination would have a index of refraction change of X. One could choose to store only one data page at a particular location, which would lead to a very high diffraction efficiency of the readout beam, and thus a high intensity of the image beam. This very high diffraction efficiency will make it possible to detect this page with a high signal to noise ratio. One could also choose to store 100 pages in the same location, each data page only consuming only 1/100 of the total index budget, and therefore 100 times lower intensity of the related image beam per data page. Noise contributions in the total system with respect to the signal of the detector then determine whether the recorded data can be retrieved reliable.

Solutions and some embodiments

Now we know that the recording medium has cumulative characteristics and that a holographic data storage system can be devised in this way, one could also use this characteristic to circumvent the issues related to the data encoder.

Consider the figure below, which shows a certain amount of element (pixels) in a 2D- light modulator 10 to be described. Each element 11 having an area comprises a sub-area (window) 12 that is usually optically active and can be modulated, resulting in a change in its optical properties. Note that the window can either be transmissive or reflective. Also note that the 2D-light modulator is characterized by having a plurality of individually addressable elements, that each element has at least one sub-area smaller than the area of the element itself. In the figure these windows are drawn as squares, but can have any shape. It can also

be that not all rows of elements have identical window shapes. The same could be valid for the column.

So, above we considered a holographic data storage device for recording data encoded in bits in a holographic data storage medium (1), a number of said data bits being organized in a data page, said device comprising a data encoder (3) for forming an encoded data beam (61) of the data page, said data encoder comprising a number of individually addressable elements (11), each element having an area and at least one optically active sub-area (12) that is smaller than said area, said number of elements being at least a factor two smaller than said number of bits in said data page.

Recording can be done in several ways.

The 2D light modulator can be used in combination with a displacement of the encoded data beam 61, for instance by means of an element that can deflect the whole encoded data beam. Such an element can consist for example of liquid crystal device.

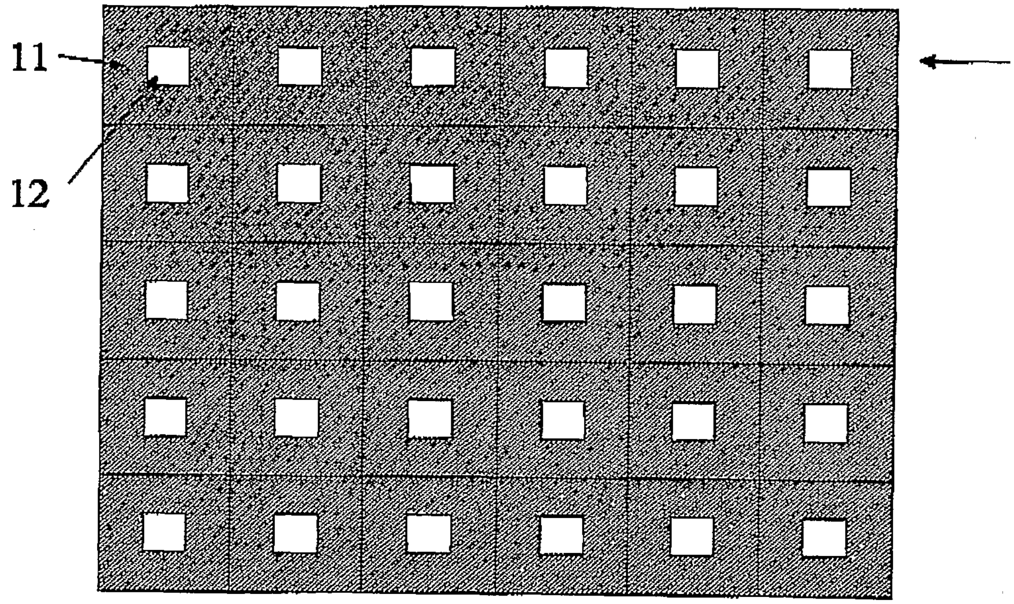
By a proper combination of exposure and displacements of the encoded data beam, a data page can be constructed, which has individual data bits determined by the windows in the 2D-light modulator, and a total count determined by the number of individual elements11 times the number of exposures needed to fill up the whole area of the element.

So, here we have proposed a holographic data storage device for recording data encoded in bits in a holographic data storage medium (1), a number of said data bits being organized in a data page, said device comprising a data encoder (3) for forming an encoded data beam (61) of said data page and an actuator for mutually displacing said medium and said encoded data beam.

In another embodiment a mechanical displacement of the whole modulator in directions perpendicular to the first optical axis will result in the same effect.
The amount of displacements as well as directions depends on the shape of the window in the elements of the 2D light modulator.

Depending on the shape of the window it can be that not the whole area of the element will be filled up, but only a substantial part.

Doing so, one can use a low pixelcount modulator and still obtain a high-resolution datapage.



The exposure process needs some clarification. Suppose we have devised a 2D light modulator in such a way that it takes 'd' displacements to fill up the whole area of element 11. If we would need 'f' fluence (J/cm2, or number of photons) to get the required change of index of refraction in the medium for the data page in case we would have the window 12 be as large as the area of the element 11, we now need to expose the material with f/d [J/cm2] in each illumination step. After 'd' steps (so, d+1 illumination steps) the whole data page is recorded, and the material is exposed with the required fluence 'f'.

One can extend this method to increase the data density even more by implementing at least a one dimensional run-length limited code. In conventional optical storage systems like CD or DVD a code is used based on the minimum size of the diffraction limited spot and small increments that are a fraction of that minimum size.

In a diffraction limited system, each pixel (or data bit) has a finite size which is determined by the modulation transfer function of the system. One can perform the same trick here, by choosing the displacement 'd' in such a way that the windows 12 in subsequent steps overlap. Care has to be taken for proper exposure.

From the above description it is also clear that during readout a low count pixilated detector could be used with similar ways to perform the scanning of the higher density recorded data page.

CLAIMS:

1. A holographic data storage device for recording data encoded in bits in a holographic data storage medium (1), a number of said data bits being organized in a data page, said device comprising a data encoder (3) for forming an encoded data beam (60) of the data page, said data encoder comprising a number of individually addressable elements (11), each element having an area and at least one optically active sub-area (12) that is smaller than said area, said number of elements being at least a factor two smaller than said number of bits in said data page.

2. A holographic data storage device for recording data encoded in bits in a holographic data storage medium (1), a number of said data bits being organized in a data page, said device comprising a data encoder (3) for forming an encoded data beam (61) of said data page and an actuator for mutually displacing said medium and said encoded data beam.

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